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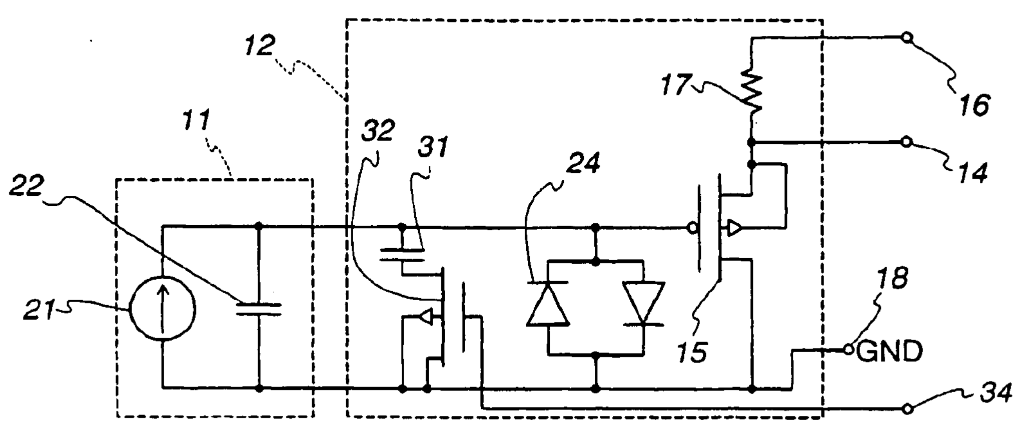
(54) Title: MICROPHONE WITH RANGE SWITCHING



(57) **Abstract:** A variable sensitivity/variable gain circuit for an electret microphone (10) having an amplifier (12) includes a sensitivity selecting circuit (32) coupled with the buffer amplifier (12) for adjusting the transduction gain of the microphone.

WO 01/78446 A1

MICROPHONE WITH RANGE SWITCHING

BACKGROUND OF THE INVENTION

This specification describes, with reference to the accompanying drawings, an improvement in electret type microphones, and more specifically, an arrangement for controllable sensitivity or gain in a microphone for a hearing aid.

Miniature electret microphones are usually fitted with an internal buffer amplifier in order to decrease the output impedance to a usable level. Because of the nature of the amplifier, the power supply voltage limits the dynamic range of the output signal. In many battery-operated applications, the supply voltage can be very low.

FIG. 1 shows a prior art hearing aid which generally includes a microphone (MIC) 10 which is a transducer for converting incoming sound pressure levels to corresponding electrical signals. A second component is a signal processing device 20 which may include an amplifier to further process the electrical signals. Finally, a receiver (REC) or loudspeaker component 30 is a transducer which receives the processed electrical signals and converts them to an acoustic output.

FIG. 2 depicts a typical electret microphone transducer or cartridge 10 with a buffer amplifier 12. The signal output terminal 14 is taken at the source electrode of a MOSFET transistor 15 in a source follower configuration, wherein the drain electrode of the MOSFET 15 is coupled to a ground terminal 18 and a source resistor 17 is coupled between a positive voltage supply terminal 16 and the source electrode of the MOSFET 15. The electret microphone cartridge 10 is depicted in equivalent circuit form as a signal/current source 21 and a parallel capacitor 22. The buffer amplifier 12 also uses a pair of bias diodes 24. The typical DC output voltage on terminal 14 is about 0.6 VDC.

The commonly used source follower amplifier 20 typically has a maximum output amplitude of 0.2 V at a supply voltage of 0.9 V. With a normal microphone sensitivity of -33 dB re. 1V/Pa, the maximum usable sound pressure at the input is about 110 dB SPL. In noisy environments (e.g., in motorized vehicles) this maximum can be too low to maintain linearity. However, input sound levels higher than this maximum will result in overloading the amplifier. Minor overloading of the amplifier will cause distortion of the signal ("clipping"). Severe overloading may force the amplifier into a saturated condition,

in which the DC level of the output is either close to the supply voltage or close to zero, and the output signal is very low. Recovery of the normal bias condition after saturation will take some time (e.g., in the order of several seconds).

A lower sensitivity microphone can be used in noisy conditions without overload, e.g., a-41 dB sensitivity results in a maximum input level of 118 dB. Such a low sensitivity, however, limits the maximum achievable signal-to-noise ratio. The noise from the buffer amplifier, and also noise from the signal processing (e.g., thermal noise from analog filtering or quantization noise from an A-to-D converter) adds to the microphone output signal level. If, for example, these noise sources contribute an input equivalent noise of 22 dB SPL at -33 dB sensitivity, the contribution will be 30 dB SPL at -41 dB sensitivity.

SUMMARY OF THE INVENTION

The present invention improves on the above situation by providing a sensitivity or transduction gain adjustment, such as an attenuator between the electret microphone cartridge 10 and amplifier 12. The attenuator may be controllably varied according to the signal level, for example, to attenuate the signal less, or not at all below a certain signal level. One purpose of the attenuator is to protect the amplifier 20 from overload.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a functional block diagram of a typical hearing aid;

FIG. 2 is a circuit schematic of a prior art microphone for a hearing aid;

FIG. 3 is a circuit schematic of a microphone in accordance with one embodiment of the invention;

FIG. 4 is a circuit schematic of a microphone in accordance with another embodiment of the invention;

FIG. 5 is a functional block diagram of the microphones of FIGS. 2 and 3;

FIG. 6 is a functional block diagram similar to FIG. 4 showing an additional decoder;

FIG. 7 is a functional block diagram similar to FIG. 5 showing an additional memory component;

FIG. 8 is a functional block diagram similar to FIG. 4 showing an additional level detector;

FIG. 9 shows a microphone employing circuitry similar to that of FIGS. 3 and 5;

FIG. 10 shows further details of the embodiment of FIG. 6;

FIG. 11 shows further details of the embodiment of FIG. 7;

FIG. 12 shows further details of the embodiment of FIG. 8; and

FIG. 13 shows an embodiment of the invention further including an analog-to-digital converter.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENT

FIG. 3 depicts a first embodiment of the invention. An attenuator in the form of an impedance such as a capacitor 31 is added to the microphone assembly of FIG. 2. Use of a capacitor as the attenuating impedance is advantageous in that it does not affect the frequency response of the microphone. The capacitor can be switched on and off by means of an electronic switch 32, which is controlled by the voltage on a control terminal 34. With the switchable capacitor having a capacitance on the same order of magnitude as the capacitance of the microphone cartridge and the input capacitance of the buffer (a few pF), the sensitivity (or transduction gain) of the microphone assembly can be decreased by several dBs. In FIG. 3, the switch 32 includes a second MOSFET having its source electrode coupled to the capacitor 31, its drain electrode coupled to ground, and its gate electrode coupled to the control terminal 34. The capacitor 31 and switch 32 may be incorporated in the buffer amplifier chip 12.

FIG. 4 depicts a second embodiment employing an approach different from the source follower-type buffer amplifier of FIGS. 2 and 3. In FIG. 4, a common source amplifier configuration 12a is used. Terminals 14, 16 and 18 are used for signal output, supply voltage and ground respectively. The MOSFET 15 and a bias (drain) resistor 17a form an inverting amplifier, of which the gain is set by a feedback capacitor 38.

The negative feedback can be increased by switching in the capacitor 31. The capacitor 31 can be switched in and out of the circuit by means of an electronic switch 32a, which is controlled by the voltage on a control terminal 34a. In FIG. 3, the switch 32a is shown as a MOSFET with a gate electrode coupled to the control terminal 34a and the source-drain path between the output signal terminal and the capacitor 31.

The above-described arrangements offer some additional advantages, including:

larger dynamic range;

better use of the dynamic range of an A-to-D converter (to be discussed later); and ability of the microphone to operate at higher sound levels.

FIG. 5 illustrates, in somewhat functional form, the concept of dynamic range switching according to the examples given in FIG. 3 and FIG. 4. As mentioned above, the switching of an impedance element such as the capacitor 31 into and out of the circuit can correspondingly vary the overall sensitivity of the assembly, acting as an attenuator or sensitivity adjustment, or as a (transduction) gain control arrangement. Thus, in FIG. 5, the electret cartridge 10 and the buffer amplifier 12 produce an electrical output signal at output terminal 14, in response to the sound pressure level experienced at the microphone 10. The sensitivity control circuitry or arrangement is symbolized at reference numeral 40 in FIG. 4, and is responsive to a control signal on control terminal 34 for selecting the dynamic range or sensitivity of the overall system. A feedback signal 42, shown in phantom line in FIG. 4 may also be employed.

Referring now to FIG. 6, a further variation on the arrangement of FIG. 5, namely, a programmable sensitivity arrangement, is illustrated in functional block form. In this arrangement, the sensitivity control circuit 40 is controlled indirectly from the control input 34 by an intervening decoder device 44. In this case, the sensitivity or gain control circuit 40 may have more than two settings or values (on/off as in FIGS. 3 and 4) and may be a multiple sensitivity stepped device (for example, eight steps of 3 dB each). The decoder 44 is connected to a control terminal 34 which might be a serial code input terminal for driving the decoder to select a suitable sensitivity or gain setting of the circuit 40, for example, by switching or selecting among a plurality of impedance elements of various values, or by selecting the setting of a variable impedance device.

Referring to FIG. 7, a circuit similar to FIG. 6 is shown. However, in the circuit of FIG. 7, the sensitivity setting is programmable and may be programmed or stored in a non-volatile memory component 46 which is operatively coupled with the decoder 44. Thus, the decoder 44, in response to the control input signal at input 34, may enter a value or setting, to be stored in the memory 46, as well as decode a previously stored setting into a signal suitable for achieving this setting in the circuit 40, when desired.

Referring to FIG. 8, a circuit is shown in which the sensitivity setting at the circuit 40 is achieved in cooperation with a level detection circuit 50. The circuit 50 detects the signal level at the buffer amplifier output 14 and may produce a switching voltage for switching an impedance element such as a capacitor, similar to the circuits of FIGS. 3 and 4, into and out of the circuit when the output level exceeds or falls below some preselected switching level at which a change in sensitivity or gain is desired. For example, a control signal might be produced for switching the attenuator or capacitor into the circuit when the output exceeds a level corresponding to a 100 dB sound pressure input level, and may be set to remove the attenuator or capacitor from the circuit when the sound level drops below a level corresponding to a 90 dB input sound pressure level. An additional output terminal 52 may be provided for the level detector device 50 for making the signal output of this level detector 50 available for external signal processing. It will be noted that with respect to the embodiments of FIGS. 6 and 7, the control signal input to the decoder might also be derived from an output level detector such as the level detector 50 of FIG. 8, whereby multiple sensitivity or gain levels might be achieved by selecting multiple switching levels from the level detection device 50.

FIG. 9 shows a more detailed schematic diagram of a circuit similar to that of FIGS. 3 and 5. In FIG. 9, the electronic switch 32 for switching the capacitor 31 is driven by a Schmitt-trigger 60. If the input 34 is driven to a low level, the switch 32 is disabled and the sensitivity is in the standard (high) range. If the input is driven to a high level the switch 32 is enabled, thus the capacitor 31 is switched in parallel with the amplifier input and the sensitivity is in the low range.

FIG. 10 shows a more detailed diagram of the circuit of FIG. 6. In this figure there are multiple range switching devices 32a, 32b . . . 32n and associated capacitors 31a, 31b . . . 31n. With, e.g., 3 range switching devices, with 3, 6 and 12 dB sensitivity steps, 8 sensitivity ranges can be obtained. All switches 32a . . . 32n are driven by a decoder 44. The decoder 44 can have either *n* parallel inputs 34 for 2^n sensitivity ranges, or one serial input signal. Various solutions for the serial or parallel interface are well known in the field of IC engineering.

FIG. 11 shows a more detailed diagram of a portion of the circuit of FIG. 7. In FIG. 11, a plurality of capacitors 31a . . . 31n and switches 32a . . . 32n are used, as in FIG. 10. The decoder 44 for the range switching devices 32a . . . 32n receives its input

from a non-volatile memory 46, which may be incorporated in the buffer amplifier chip 12. A serial or parallel interface 72 enables programming of the sensitivity setting in the memory 46. The sensitivity setting can be programmed during manufacturing, in which case a programming input 74 may be omitted, or during operation, i.e., in the field. The advantages of sensitivity programming during manufacturing are the possiblity of producing microphones of different sensitivity classes with one design, and the possibility of accurately calibrating the sensitivity level of the microphone to an exact value. With e.g. 4 range switching devices, with 0.3, 0.6, 1.2 and 2.4 dB sensitivity steps, the microphone sensitivity can be tuned within 0.2 dB with a maximum of 4.5 dB, which feature is very useful for applications where matched microphones are applied.

FIG. 12 shows a more detailed diagram of a portion of the circuit of FIG. 8. In FIG. 12, the buffer amplifier circuit components are symbolized at reference numeral 12a. The output signal of the amplitude detector 50 is proportional to the sound pressure level at the input of the microphone. A low-pass filter (LPF) 80 averages the signal during a certain period (a few tenths of a second up to a few seconds). The level detection operation is completed by a Schmitt trigger 82, which drives the electronic switch 32, and also the output terminal 52. The circuit is switched to a lower sensitivity level after the average sound pressure exceeds a certain level (eg. 100dB), and returns to the normal sensitivity level after the average sound pressure drops below a lower level (eg. 90 dB). This arrangement can be extended to use with multiple range switches and automatic switching on multiple levels, as in FIGS. 10 and 11.

The feature of automatic range switching is very useful in combination with an integrated A-to-D converter (ADC), that is, one that is part of the microphone 10, for example on the same chip and/or board as the buffer amplifier 12. Such an arrangement is indicated in FIG. 13. When an ADC (A/D) 90 (see FIG.13) is used, the functions of the amplitude detector 50, low-pass filter 80 and Schmitt trigger 82 can be connected after the ADC and be implemented digitally. As shown in FIG. 13, the output signal from the Schmitt-trigger 82, and the output stream from the ADC 90 are combined at logic 94 to a single output format at output 52a.

As indicated above, in FIG. 13, the microphone has a built-in A-to-D converter 90. The converter can be integrated on the same IC as the buffer amplifier and range switching devices, or can be on a separate IC. Here, the range switching can be used to

prevent the A-to-D converter from overflow on high sound levels, and to increase the resolution of the converter for low sound levels. A factory programmable sensitivity range selection as previously described can also be employed in order to tune the microphone sensitivity for optimal use with an ADC, and store the sensitivity value or setting, or a code prepresenting the value or setting, in a non-volatile memory, so that the ADC input range matches a well-defined sound pressure level. The "on board" ADC can also be combined with the other embodiments shown and described herein.

The various embodiments of the invention also provide ways to extend the dynamic range of the A-to-D converter.

While particular embodiments and applications of the present invention have been illustrated and described, it is to be understood that the invention is not limited to the precise construction and compositions disclosed herein and that various modifications, changes, and variations may be apparent from the foregoing descriptions without departing from the spirit and scope of the invention as defined in the appended claims.

WHAT IS CLAIMED IS:

1. An electret microphone comprising:

a transducer responsive to incoming sound pressure for producing a corresponding electrical signal;

an amplifier receiving said electrical signal and producing a low-impedance output signal; and

a sensitivity selecting circuit coupled between said transducer and said amplifier for adjusting the sensitivity of said microphone.

2. The electret microphone of claim 1 wherein said sensitivity selecting circuit comprises at least one impedance element, and a selection circuit operatively coupled with said at least one impedance element for selecting the effective value of said at least one impedance element.

3. The electret microphone of claim 2 wherein said impedance selection circuit is responsive to said output signal for selecting the value of the impedance in such a manner as to provide a greater gain for said microphone in response to output signals corresponding to a first range of sound pressure levels and a second gain, less than said first gain, in response to output signals corresponding to sound pressure levels greater than said first range.

4. The electret microphone of claim 2 wherein the effective value of said at least one impedance element is variable and wherein said selection circuit selects said effective value of said impedance.

5. The electret microphone of claim 2 wherein said at least one impedance element comprises a fixed impedance element and a switching circuit for switching said at least one impedance element into and out of circuit with said amplifier, with the transduction gain of said microphone being relatively lower with said impedance element in said circuit therewith and relatively higher with said impedance element out of circuit therewith.

6. The electret microphone of claim 5 wherein said switching circuit is responsive to an externally applied control voltage for switching said at least one impedance into and out of circuit with said amplifier.

7. The electret microphone of claim 2 wherein said sensitivity selecting circuit includes a decoder circuit responsive to a control voltage for selecting the effective value of said at least one impedance element.

8. The electret microphone of claim 7 and further including a memory for storing sensitivity selection information for selection by a said decoder.

9. The electret microphone of claim 2 wherein said at least one impedance element comprises a capacitor.

10. The electret microphone of claim 3 wherein said sensitivity selecting circuit includes a signal level detector circuit coupled with an output of said amplifier for producing a sensitivity selection signal in response to the signal level output of the buffer amplifier.

11. The electret microphone of claim 5 wherein said at least one impedance element comprises a plurality of impedance elements of selected values and wherein said switching circuit is capable of switching one or more of said impedance elements into or out of circuit with said amplifier to provide a plurality of sensitivity settings.

12. The electret microphone of claim 1 wherein said microphone further includes an analog-to-digital converter coupled with said amplifier for converting the output thereof to digital form, whereby said sensitivity selecting circuit further extends the dynamic range of the analog-to-digital converter.

13. The electret microphone of claim 5 wherein said microphone further includes an analog-to-digital converter coupled with said amplifier for converting the

output thereof to digital form, whereby said sensitivity selecting circuit further extends the dynamic range of the analog-to-digital converter.

14. The electret microphone of claim 7 wherein said microphone further includes an analog-to-digital converter coupled with said amplifier for converting the output thereof to digital form, whereby said sensitivity selecting circuit further extends the dynamic range of the analog-to-digital converter.

15. The electret microphone of claim 8 wherein said microphone further includes an analog-to-digital converter coupled with said amplifier for converting the output thereof to digital form, whereby said sensitivity selecting circuit further extends the dynamic range of the analog-to-digital converter.

16. The electret microphone of claim 10 wherein said microphone further includes an analog-to-digital converter coupled with said amplifier for converting the output thereof to digital form, whereby said sensitivity selecting circuit further extends the dynamic range of the analog-to-digital converter.

17. A hearing aid comprising:

a microphone including a transducer responsive to an incoming sound pressure for producing a corresponding electrical signal and an amplifier for producing an output signal;

a signal processor for processing the output signal received from the amplifier to produce a processed signal;

a receiver responsive to said processed signal for producing a corresponding audio output; and

a sensitivity selecting circuit coupled with said microphone for adjusting the sensitivity of said microphone.

18. The hearing aid of claim 17 wherein said sensitivity selecting circuit comprises at least one impedance element, and a selection circuit operatively coupled with

said at least one impedance element for selecting the effective value of said at least one impedance element.

19. The hearing aid of claim 18 wherein said impedance selection circuit is responsive to said output signal for selecting the value of the impedance in such a manner as to provide a greater transduction gain for said microphone in response to output signals corresponding to a first range of sound pressure levels and a second transduction gain, less than said first transduction gain, in response to output signals corresponding to sound pressure levels greater than said first range.

20. The hearing aid of claim 18 wherein the effective value of said at least one impedance element is variable and wherein said selection circuit selects said effective value.

21. The hearing aid of claim 18 wherein said at least one impedance element comprises at least one fixed impedance element and said selection circuit comprises a switching circuit for switching said impedance element into and out of circuit with said amplifier, with the transduction gain of said microphone being relatively lower with said impedance element in circuit therewith and relatively higher with said impedance element out of circuit therewith.

22. The hearing aid of claim 21 wherein said switching circuit is responsive to an externally applied control voltage for switching said at least one impedance element into and out of circuit with said amplifier.

23. The hearing aid of claim 20 wherein said sensitivity selecting circuit includes a decoder circuit responsive to a control voltage for selecting the effective value of said at least one impedance element.

24. The hearing aid of claim 23 and further including a memory for storing sensitivity selection information for selection by a said decoder.

25. The hearing aid of claim 18 wherein said at least one impedance element comprises a capacitor.

26. The hearing aid of claim 19 wherein said sensitivity selecting circuit further includes a signal level detector circuit coupled with an output of said amplifier for producing a sensitivity selection signal in response to the signal level output of the amplifier.

27. The hearing aid of claim 17 wherein said microphone further includes an analog-to-digital converter coupled with said amplifier for converting the output thereof to digital form, whereby said sensitivity selecting circuit further extends the dynamic range of the analog-to-digital converter.

28. The hearing aid of claim 21 wherein said microphone further includes an analog-to-digital converter coupled with said amplifier for converting the output thereof to digital form, whereby said sensitivity selecting circuit further extends the dynamic range of the analog-to-digital converter.

29. The hearing aid of claim 23 wherein said microphone further includes an analog-to-digital converter coupled with said amplifier for converting the output thereof to digital form, whereby said sensitivity selecting circuit further extends the dynamic range of the analog-to-digital converter.

30. The hearing aid of claim 24 wherein said microphone further includes an analog-to-digital converter coupled with said amplifier for converting the output thereof to digital form, whereby said sensitivity selecting circuit further extends the dynamic range of the analog-to-digital converter.

31. The hearing aid of claim 26 wherein said microphone further includes an analog-to-digital converter coupled with said amplifier for converting the output thereof to digital form, whereby said sensitivity selecting circuit further extends the dynamic range of the analog-to-digital converter.

32. The hearing aid of claim 21 wherein said at least one impedance element comprises a plurality of impedance elements of selected values and wherein said switching circuit is capable of switching one or more of said impedance elements into or out of circuit with said amplifier to provide a plurality of sensitivity settings.

33. A method of operating an electret microphone comprising:

responding to incoming sound pressure at a transducer and producing a corresponding electrical signal;

receiving said electrical signal at an amplifier and producing a low-impedance output signal; and

adjusting the sensitivity of said microphone at a sensitivity selecting circuit between said transducer and said amplifier.

34. The method of claim 33 wherein said adjusting comprises adjusting the effective value of said at least one impedance element located between said transducer and said amplifier.

35. The method of claim 34 wherein said adjusting comprises adjusting the effective value of said at least one impedance element responsive to said output signal, selecting the effective value in such a manner as to provide a greater gain for said microphone in response to output signals corresponding to a first range of sound pressure levels and a second gain, less than said first gain, in response to output signals corresponding to sound pressure levels greater than said first range.

36. The method of claim 34 wherein selecting the effective value of said at least one impedance element comprises switching said at least one impedance element into and out of circuit with said amplifier.

37. The method of claim 36 including applying a control voltage to control said switching said at least one impedance into and out of circuit with said amplifier.

38. The method of claim 36 including decoding said control voltage for selecting the effective value of said at least one impedance element.

39. The method of claim 38 and further including storing sensitivity selection information in a memory for use in said decoding.

40. The method of claim 35 including detecting a signal level of an output of said amplifier and producing a sensitivity selection signal in response to the signal level output of the amplifier.

41. The method of claim 33 further including converting the output of said amplifier to digital form, whereby said sensitivity selecting circuit further extends the dynamic range of said converting.

Fig. 1
(Prior Art)

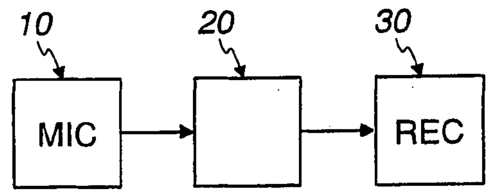


Fig. 2
(Prior Art)

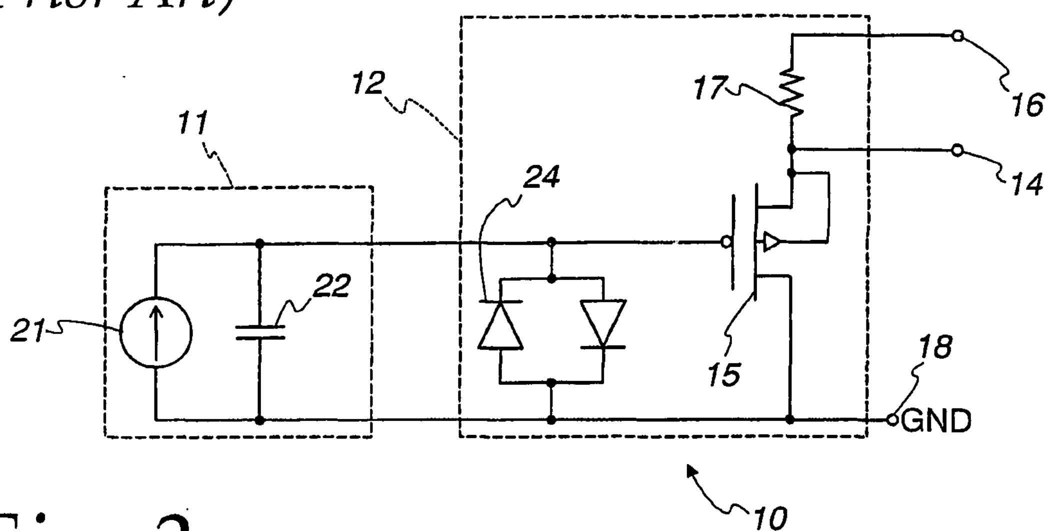


Fig. 3

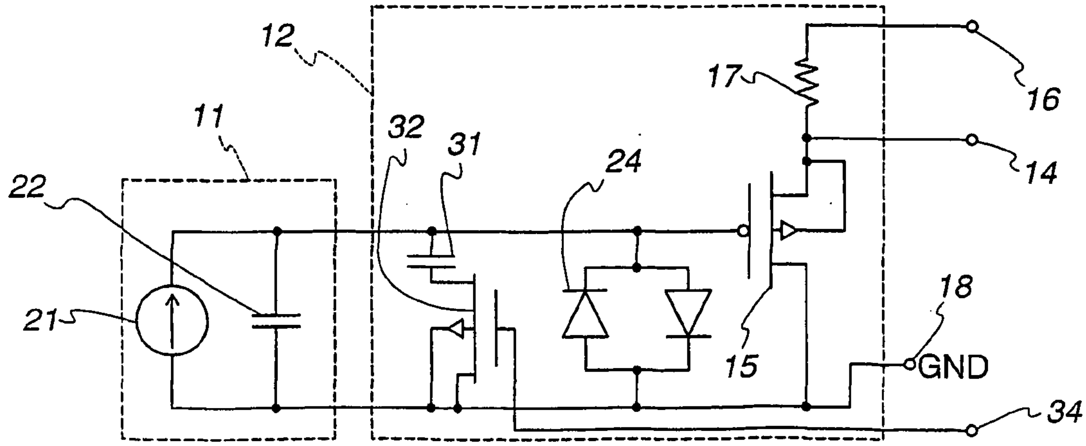


Fig. 4

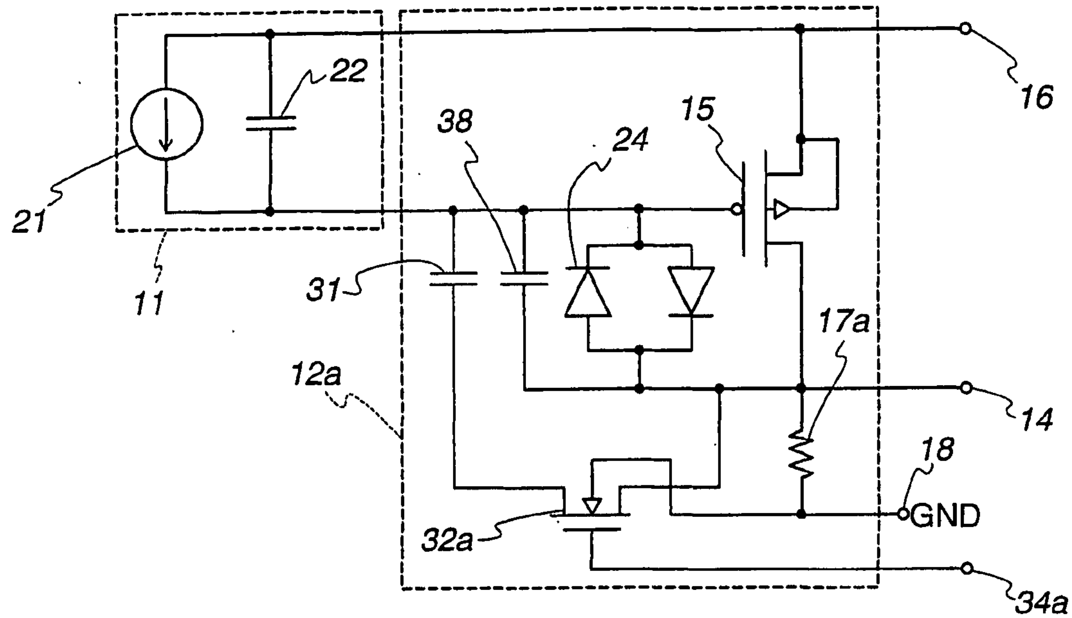


Fig. 5

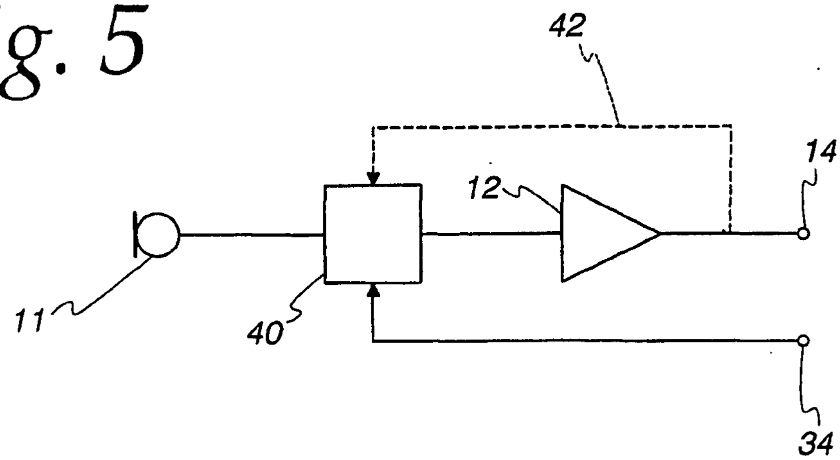


Fig. 6

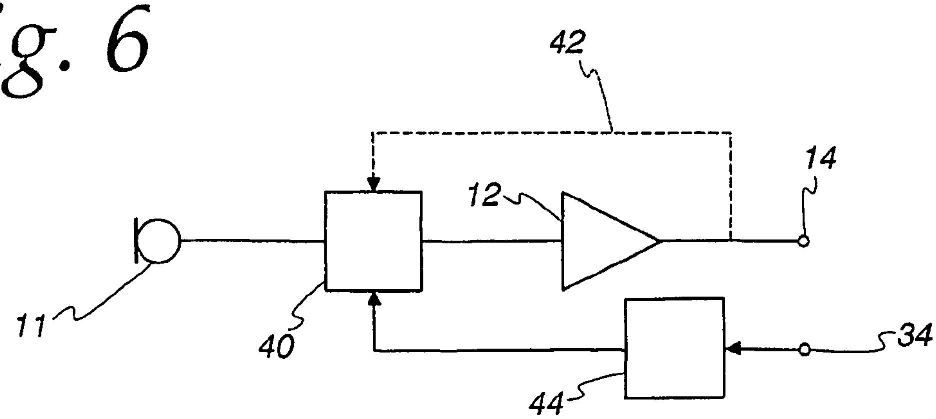


Fig. 7

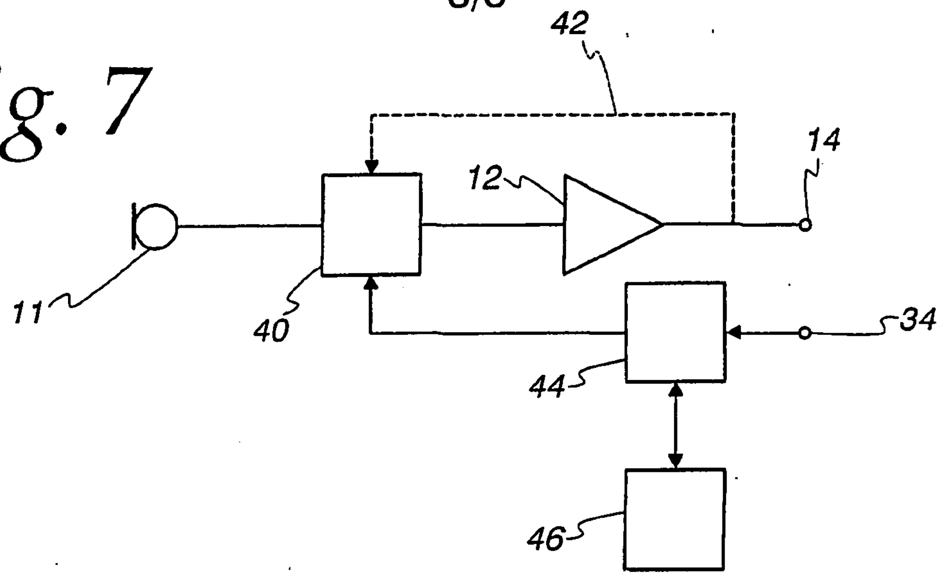


Fig. 8

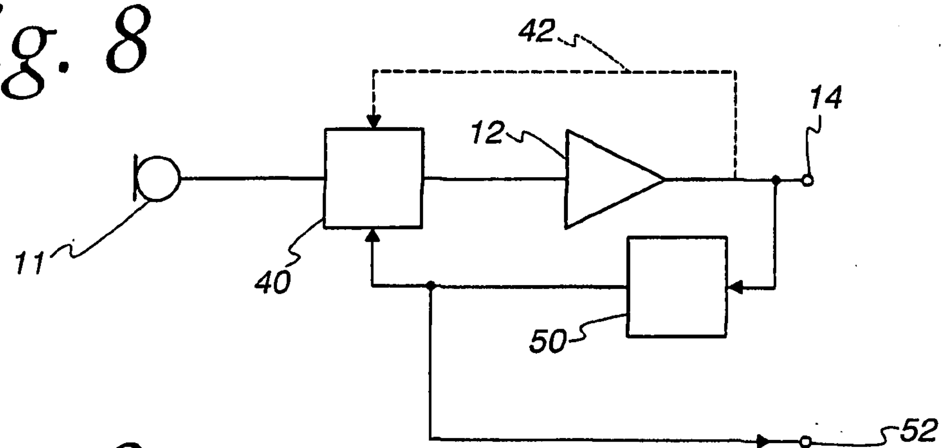


Fig. 9

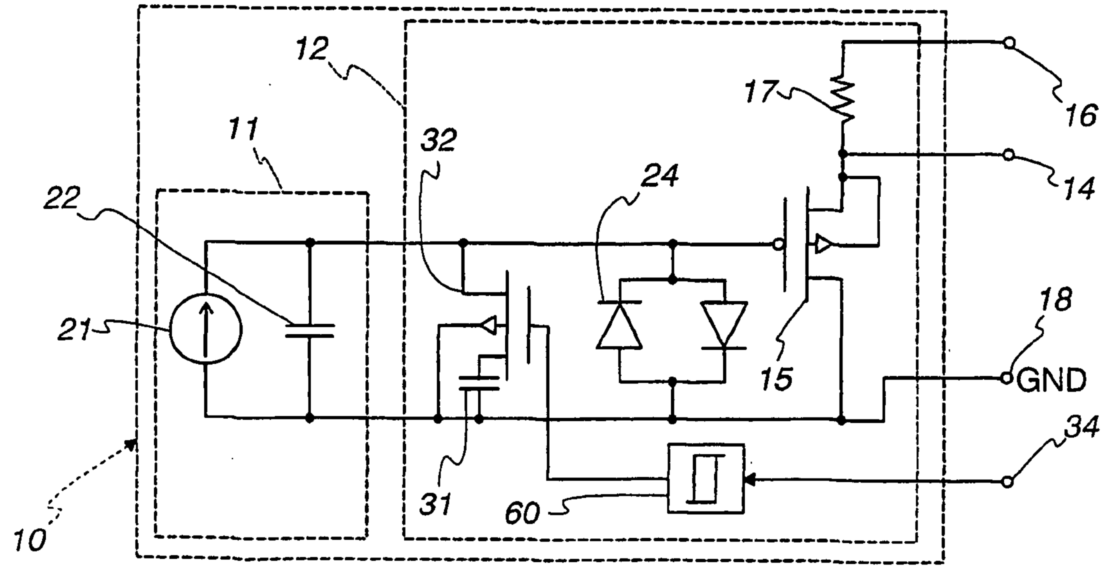
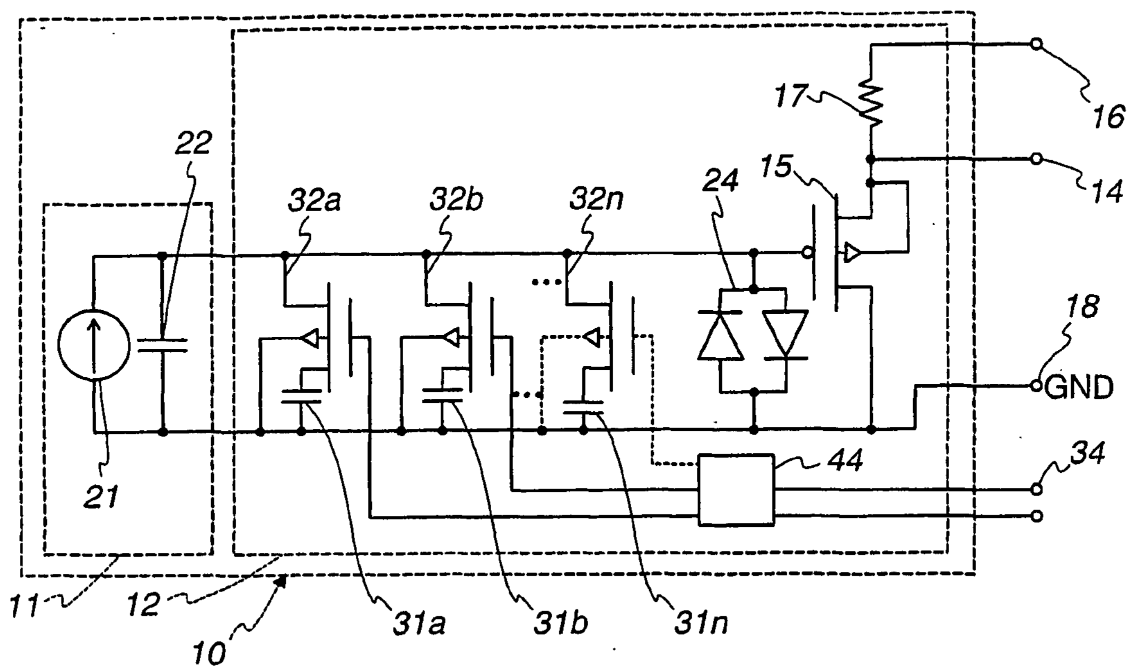


Fig. 10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15
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11
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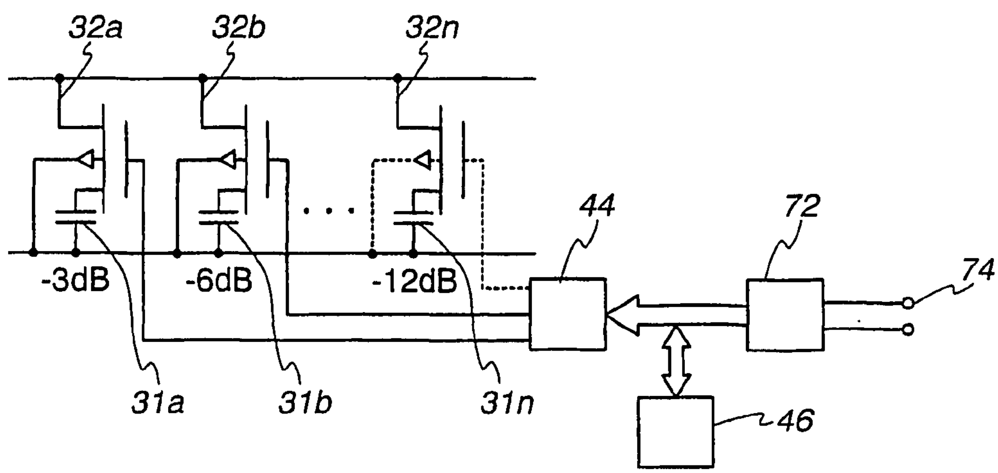
Fig. 11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74
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31b
31n
46

Fig. 12

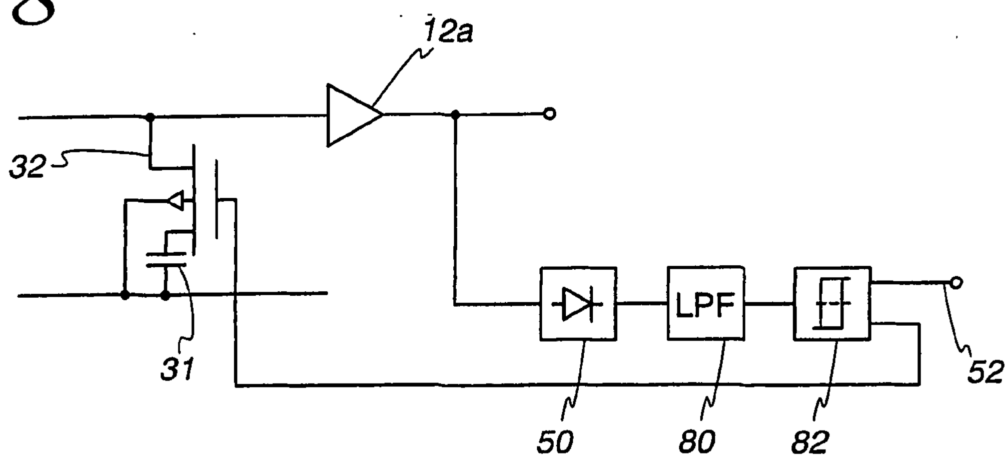
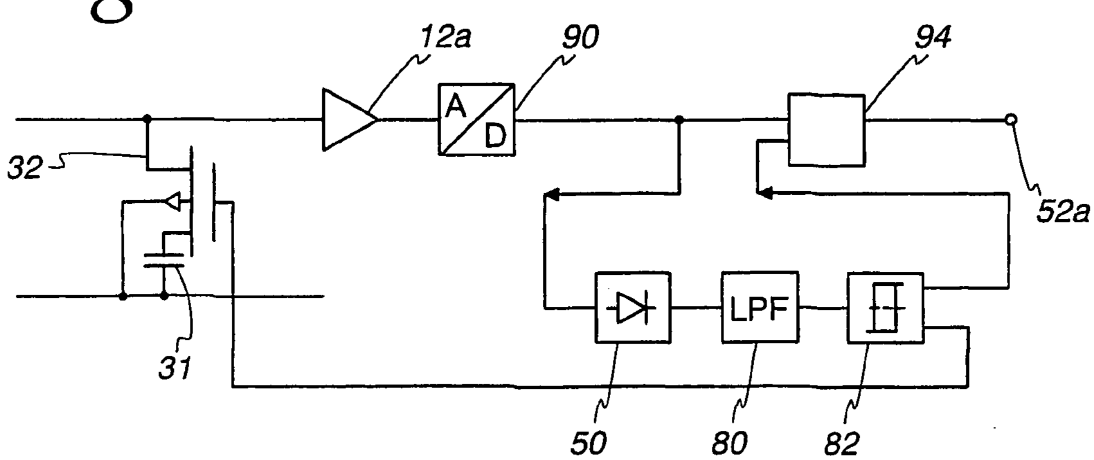


Fig. 13



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/09475

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :H04R 3/00, 25/00, 21/02
US CL :381/369, 174, 92, 111, 112, 114
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 381/369, 174, 92, 111, 112, 114

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	US 6,084,972 A [VAN HALTEREN et al] 04 July 2000, figs. 1A-1B.	1-41
A	US 4,582,961 A [FREDERIKSEN] 15 April 1986, figs. 3-7.	1-41

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search

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